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BIOGAS CONVERSION ASSESSMENT PROJECT

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BIOGAS CONVERSION ASSESSMENT PROJECT

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1. INTRODUCTION

1-1 Project Purpose and Conditions of Compliance

Montana State University and the National Center for Appropriate Technology jointly received a grant of $25,624 from the Montana Department of Natural Resources and Conservation under the Alternative Renewable Energy Sources Program to investigate the feasibility of biogas generation from agricultural wastes in the State of Montana. The goals of this project are: (1) to evaluate the state of current biogas generation technology, and (2) to develop specific biogas applications suitable to the particular climatic, economic and demographic conditions of the State of Montana. Three specific tasks are to be conducted under this project: (1) an assessment of existing biogas hardware and technology with particular emphasis on the technology's relevance to various Montana agricultural subsectors; (2) a site evaluation for the location of a prototype developmental digester; and, (3) the development of a preliminary engineering design for a digester to be located at a specific site in Montana.

The goal of the Alternative Renewable Energy Sources Program is to promote the development and widespread use of renewable energy in Montana. Funds from the program are utilized for a variety of purposes related to this long-term goal. These purposes reflect the fact that renewable energy technologies are in various, uneven stages of development and require different kinds of encouragement. Funded projects include basic research, a multitude of applied research projects, and proposals designed primarily for education and technology transfer. All of these projects have in common the acknowledgement that, if the goal of widespread implementation of renewable energy technologies is indeed considered to be in the public interest, then selective public subsidies are justified at all stages of development.

Under this assumption, funds will be sought for the construction of a pilot facility to demonstrate the potential for conversion of agricultural animal wastes to methane in the State of Montana.

The question of bioconversion feasibility is important in Montana, where agriculture is central to the economic well-being of the State and also is the core of a way of life commonly seen as worth preserving. Montana is currently under pressure to expand coal production while sustaining agricultural output. This poses a conflict, as both agriculture and energy development increasingly compete for use of primary resources such as land and water. Further, agriculture is a direct user of energy. If maintenance of the Montana agricultural base is important, then more efficient energy utilization in agriculture must become a goal.

It must be recognized at the outset that the decision to finance construction of a digester cannot be reduced simply to the question of technological feasibility. The design project envisaged is intended to provide impetus for continuous experimentation, hopefully with a variety of biogas conversion projects across Montana, toward the goal of improving technological efficiency.

The question also cannot be simply whether or not the pilot is economical. The real economic costs of a biogas conversion system are difficult to estimate, both because of the subsidies and ceilings which distort the current price of non-renewable fuels, and because of the unknown level of future subsidies of renewable energy. The decision involves estimating the long term potential for the displacement of current non-renewable fuel consumption in Montana and, thus, calculating the expected value of a demonstration project in spurring continuous interest in attaining that long range goal. This particular project serves both as a technology development/demonstration project and as a technology transfer project to spark additional experimentation or construction of production units.

1-2 Summary of Interim Report Findings

In the Interim Report of January 15, 1979 the NCAT - MSU Biogas Conversion Assessment Project team concluded that dairy operations constituted the subsector of Montana agriculture most suitable for the early placement of a biogas digester. Comparative advantages over other subsectors included such considerations as the larger number of dairy operations, a higher potential for technology transfer, a greater proportion of recoverable waste and ease of recovery, a higher potential positive externalities of pollution control, a lower probability of digester failure and a greater potential for utilization of fuel produced.

1-3 Activities Subsequent to the Interim Report

Subsequent to the submission of the Interim Report the Biogas team established criteria for the selection of a particular dairy operation for location of a digester. These criteria, as follows, were communicated to the Department of Natural Resources and Conservation on February 15, 1979:

1. Access to the operation by the research team. This is important to the extent that the operating digester is viewed more as a development project than as a demonstration project.

2. Ability to adapt the existing operation to certain design requirements such as manure collection; the overall layout must be suitable for integrating a digester.

3. Size of the operation: Is it large enough to supply a minimum manure level while remaining typical of Montana dairy operations?

4. Ability, willingness of the owner to maintain/operate the digester. Is there access to machinery, expertise?

5. Other characteristics that will minimize the level of the grant request to build the digester.

6. Liability.

Application of these criteria led to the conclusion that most operating dairy farms in Montana currently are not large enough for the siting of an economic methane digester. Considerable research and developmental work will be necessary in order to enhance the methane production process before any full-scale demonstration project is in order. Recent research at Montana State University shows considerable promise in increasing methane output. Therefore, it was concluded that the next step should be a pilot scale development digester to be constructed at the MSU dairy farm. The project team performed an on-site assessment of the dairy operation in August and concluded that no substantial obstacles existed.

1-4 Findings and Recommendations

Choice of the MSU Dairy Center as the site of a pilot digester is supported by these favorable factors:

1. A dairy operation in situ.

2. Availability of many sources of cellulosic materials, including wheat straw, barley straw, waste paper, etc. as well as various sources of animal manures; viz cattle, hog, human and poultry.

3. Expertise in the various disciplines of engineering, agriculture, microbiology, chemistry, economics and political science are readily available. Thus, problems can receive immediate attention.

4. The coordination of the laboratory investigations and the pilot plant studies is of primary importance. The facilities for the laboratory scale studies are well established. This is a bonus situation because experimental parameters could be checked at laboratory scale prior to running plant scale investigations. The information gains would have an immediate effect which may not occur if the plant were to be located elsewhere in the state.

The MSU dairy operators and related academic faculty have expressed cooperation, interest, and enthusiasm in the project.

The decision to propose construction of a pilot scale digester is believed to be the appropriate response to existing constraints in the area of methane production research, technological advance and economics. If the methane production increases achieved in the laboratory hold in part at the pilot scale, and if cost reductions in operations can be achieved through experiments with component parts, it is projected that biogas from agricultural wastes can become marginally competitive with expected rising prices of conventional fuels. Without benefit of these assumptions, it appears that cost-effective biogas production is a long way off in Montana.

The optimal facility at this stage of development appears to be partway between laboratory research and an operating demonstration digester. Construction of a 30,000 gallon digester will allow for scaling up the research on methane output while allowing for some experiments with component system parts approximating a regular dairy operation.

2. PROJECT JUSTIFICATION AND GOALS

2-1 Rationale for a Research and Development Digester in Montana

The consensus of research on the question of biogas digestion from farm animal wastes is that immediate economic production is probably possible only with very large confined herds of animals and by taking generous credits for waste disposal. However, most dairy herds in Montana are smaller than the threshhold size, (400 head). Other ways must be found to make biogas conversion cost-effective. Potential gains are to be found in expanding the methane production through different mixtures of waste products, designing cheaper component conversion systems and exploring alternate uses of digester residue. For the combination of these goals, a development scale (post-laboratory, pre-commercial) system is best-suited. In addition, the system serves as a test of digester operation under severe climatic conditions and affords some demonstration exposure.

2-2 Expanded Methane Production Potential

Recent MSU laboratory experiments suggest there is great promise of significantly expanding methane production in biogas digester systems through mixtures of manure and cellulosic material. Tests have been conducted with various mixtures of manure, wheat straw (normal and de-lignified) and waste paper. A combination of 5% manure and 3% cellulose in the range of 6-10% total solids load produced an output of 278% of the control manure digest. These results occur under conditions utilizing 3.2 liter volumes and machine-blended waste products. (Robbins, 1979).

The high yields achieved in the laboratory warrant further investigation at the pilot-plant scale. There is no doubt that the laboratory-scale production rates are obtained under near-ideal conditions, and

and reduced yields would be expected under pilot-plant operating conditions. (i.e. less stringent control procedures, less complete blending of the waste inputs, and less control of particle size). It is necessary to evaluate the yield differences between the pilot plant scale and laboratory scale operations to determine how much of the increase could be maintained in a commercial operation.

The economics of small-scale, on-farm methane production by means of conventional manure-only digester systems is currently a significant barrier to widespread adoption. However, an increase in production rates by a factor of two, as may be obtained in the pilot-plant, would warrant an economic re-evaluation of biogas production for many dairy farms. Thus, if a third of the waste material volume could be supplied by readily available plant material then the threshhold of the dairy size can be lowered.

The facility will be used to evaluate pilot-plant scale performance:

1. for mixtures of crop residues and animal manures;
2. for mixtures of waste paper and animal manures;
3. for mixtures of waste paper and municipal sewage; and
4. for mixtures of animal manures and municipal sewage.

All of the above will be compared to laboratory scale experiments for efficiency of solid conversion and gas production at different loading concentrations and retention times. The pilot facility will be used to confirm whether the laboratory finding of more stable fermentation (lower probability of digester failure) holds when the scale of operations is increased.

2.3 Component Testing

At the pilot-plant scale, certain components may be identified which, through redesign and other cost-saving measures, may help improve the system's gas production efficiency, as well as reduce initial capital costs. Of particular concern are the functions of the system's shredder and grinding pump. Particle size is expected to be a key variable in the level of biogas production. The finer the cellulosic material can be ground, the nearer the methane production rates of the pilot-plant may approach laboratory results. In addition, one of the proposed methods for effluent handling — temporarily storing digester slurry in a relatively small holding tank and then regularly pumping the slurry onto fields -- represents a significant cost-saving design compared to most biogas digester systems.

2.4 Appropriate Uses of Digester Residue

Another major objective of the study will be to evaluate appropriate uses of digester effluent, and determine potential waste management benefits. For example, there may be significant benefits in a "weed-seedless" manure fertilizer, in which most of the weed seeds in the influent manure have been eliminated during the anaerobic digestion phase. If this organic material can be collected from the fields easily and inexpensively, there may be a ready market in nurseries, market gardeners and home gardeners.

2.5 Cold Climate Considerations

Many dairy farms in the United States, including those in Montana, operate under severe winter weather conditions. The heavy snowfalls and extreme temperatures will require special consideration in the design and operation of any digester system on such dairies. The proposed project would provide a testing ground for a number of cold climate considerations, including manure collection and storage in cold temperatures;

equipment reliability under harsh winter conditions; and in-system gas utilization requirements. The knowledge gained by operating a pilot-plant scale digester system through several Montana winters will suggest design and operation methods that will help remove some barriers to biogas system adoption among dairy farmers living in cold climates.

2.6 Demonstration Project

Although the proposed project has a research-based orientation, there will be a considerable spillover demonstration effect from the MSU system. The MSU Agricultural Experimental Station, of which the Dairy Center is a part, already serves a vital and recognized research and extension service for the state.

There are more than 100 dairies in the immediate region of the university. Clearly, a successful research venture at MSU will perform a valuable educational role for farmers in the region.

2.7 Additional Site Effects

The possibility also exists for a spillover effect to the MSU campus, integrating waste paper separation and handling in university dorms, cafeterias, married student housing and academic departments with the digester system operations. This program integration would arise through a related, but separate research project, one which would address some of the institutional and behavioral aspects of recycling and energy use.

3. PROPOSED SYSTEM OPERATION

3.1 General Overview

The proposed research digester would be built and operated at the MSU Dairy Production Center. The dairy has a 150-head herd, typical of most Montana dairies. Research results and economic analysis of the project, therefore, will likely be more directly relevant to Montana dairy farmers than would be a digester project operated on a much smaller or much larger scale.

Utilizing several combinations of animal manures and cellulosic materials, the proposed system will monitor biogas production from a 30,000 gallon digester. The goal will be to achieve pilot-plant scale production results as similar as possible to laboratory-scale experiments. Optimal combinations of manure-cellulose mixes for maximum biogas production will be identified. On-going tests also will be undertaken on: cold climate aspects; digester operation; system components which may be redesigned in order to reduce costs and improve biogas production efficiency; and appropriate uses of digester residue.

A small building will be built on the MSU Dairy property to house the digester tank, laboratory, and heating equipment. Biogas produced in the digester will be metered, scrubbed, compressed and stored in underground tanks. It is expected that most of the gas not required for in-system uses will be used to heat the nearby Dairy Center office and laboratory building.

The engineering and construction of the research digester system is expected to take from March to December 1980. Start-up would begin in January 1981 with experiments conducted for three successive years. The proposed project would continue until December 1983.

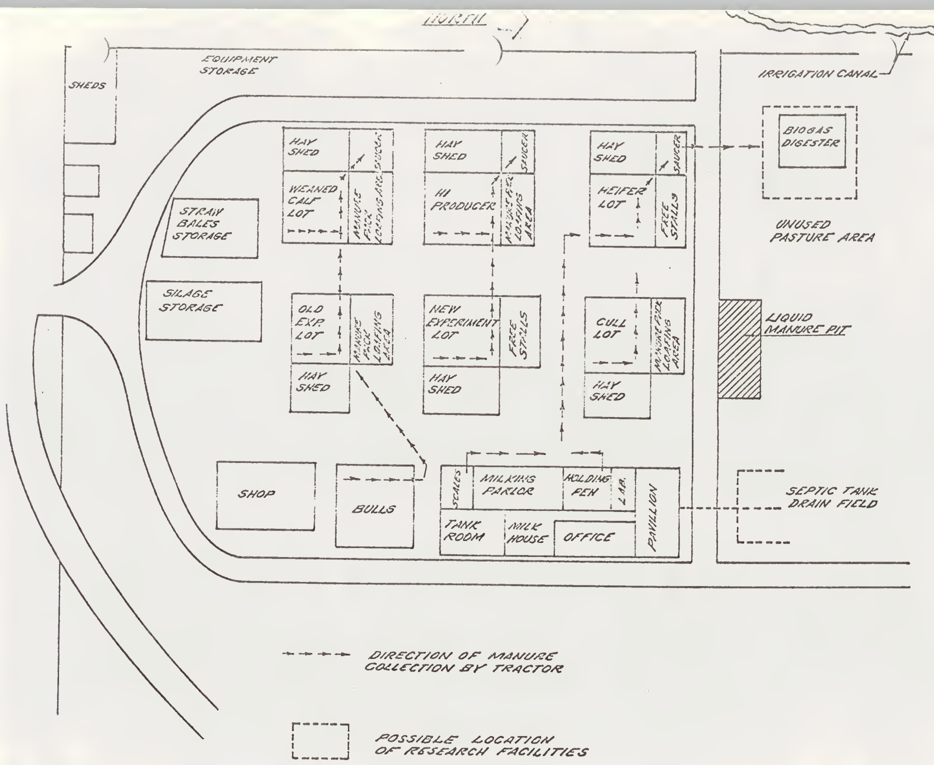

FIG. -3-1- M.S.U. -DAIRY CENTER OVERVIEW

3.2 MSU Dairy Farm Description

The MSU Dairy Production Center is located approximately one mile west of the main university campus in Bozeman, and forms part of the Agriculture Experimental Station complex. The farm, which performs both a research and educational role, has 150 head of cattle, with a milking herd of 70.

From late October until spring, the cattle are kept in six fenced lots (see Figure 3-1) which have covered loafing sheds. The concrete floors of the lots are scraped of manure daily with a rear-mounted scraper on a tractor. The collected manure is stored temporarily on three 40' X 40' concrete pads, called saucers, located on the west side of the lots. This daily cleaning job takes one farmhand about 1½ hours to complete. Every two weeks, the manure on the saucers is hauled by truck to a large manure pile, about one mile away, which serves as a storage area for most of the manure collected at the MSU Agriculture Experimental Station.

A small liquid manure pit also is located on the dairy property to handle the manure drained from the milking parlor, as well as spoiled milk and detergent used to clean the milking equipment. A tank truck occasionally empties the pit and spreads the effluent on nearby fields as fertilizer.

A detailed description of the MSU Dairy Center's existing manure disposal methods and its present energy use pattern is given in appendix A.

3.3 Proposed Biogas System Components (see Figure 3-2)

3.3.1 Project Facilities Siting

The most suitable site for the research project facilities has been identified as the large, open field on the north side of the dairy center property. The pasture, about 5 acres in size, is used only occasionally,

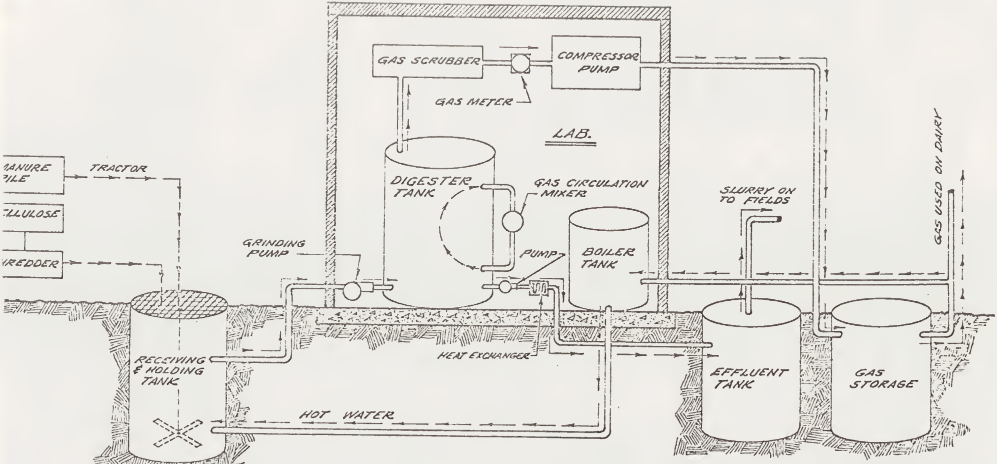

FIGURE 3-2 – SCHEMATIC DESIGN of M.S.U. DAIRY DIGESTER SYSTEM

and there are no plans for its future use. There is ample room for the building, gas storage equipment and effluent handling system required in the project. Dairy Center officials have expressed a willingness to allow as much of the open pasture land to be used for the project as required, and have promised to cooperate fully with special project needs, provided that there is no significant interference with the present Dairy Center operations.

There is one concern with the proposed site. In the past, the only significant waste management problem at the MSU dairy has been the occasional manure runoff, during spring or heavy rainfalls, from the temporary storage piles into the creek flowing alongside the dairy's northwest edge. The proposed digester project must not contribute to this problem. Indeed, one of the system's benefits may be its ability to improve overall waste management practices at the Dairy Center. Special attention, therefore, must be given in the preliminary design stage to the eventual disposal of digester effluent. (As discussed in section 3.3.7).

3.3.2 Digester Feedstocks

The primary feedstock for the digester will be manure. It is expected that the digester will use, at a maximum, the manure from the 70-head milking herd, about 5,600 pounds a day. Manure required daily by the digester system will be carried from one of the temporary storage saucers, by a front-end loader on a tractor, and dumped into the receiving and holding tank.

Municipal sewage, another major feedstock, will be available in sufficient quantities from the municipal sewage treatment facility in Bozeman.

Several alternative cellulose-based feedstocks are available at the MSU dairy center:

i) straw: Over the winter months, the MSU Dairy Center uses about

30 to 40 straw bales a day. Most of the straw is used for the loafing areas in the six lots. Straw is stored on a large concrete pad south of the lots. The proposed biogas digester system likely will use from 5 to 15 bales a day at peak operating capacity. All of the straw required by the project is expected to be available from the Dairy Center's regular suppliers and from the nearby MSU Plant and Soil Science research fields. Storage space for the straw is available on the dairy center storage pad.

ii) waste paper: The MSU Computer Center currently collects about 400 pounds a week of waste computer paper. The biogas research project could obtain most of this paper at no cost, for test purposes. Potential also exists for developing a waste paper collection program for the entire MSU campus. Waste paper could be stored in the building housing the digester tank and laboratory.

iii) spoiled feed: At certain times of the year, a relatively large volume of spoiled alfalfa silage will be available as a digester feedstock. The silage is stored in a large pile south of the fenced lots at the dairy.

iv) spoiled milk: The entire 6,000-pound contents of the milk tank occasionally must be drained to the liquid manure pit because of some error in sanitation or milking procedures. This spoiled milk would be available for digester test purposes on an irregular basis.

Shredding of the cellulose feedstocks will take place as required, either outside, or inside the laboratory building.

3.3.3 Pre-Digester Handling

The grate-covered receiving and holding tank, into which the manure and cellulose mixes are dumped, will be located adjacent to the digester building. Because the cattle lot floors are concrete, there normally will be little dirt or straw collected along with the manure. (An estimated 80 to

90 percent of the manure mix on the temporary storage piles is manure, the rest being straw). After a heavy snowfall, however, the tractor will scrape away much snow from the lots along with the manure. The impact of this collected snow on overall biogas digester system efficiency and methane production will be monitored as part of the proposed project.

With a capacity of about 8,000 gallons, the cylindrical-shaped, cement-lined tank will be built into the ground and have a removable, insulated cover to help reduce heat loss. The manure and cellulose mixes will be loaded into the tank to pre-determined levels, so that the digester operator can add the correct volume of warm water to achieve the desired percentage-volumes of solids in the tank. The influent will be mixed by means of a mechancial mixer. At anticipated peak operating capacity, about a 3,000 gallon daily mixture will be sent to the digester tank by a grinding pump.

3.3.4 Digester

A new building, approximately 1,000 square feet in area, will be required to house the digester tank, laboratory and other equipment. The insulated, rigid-top digester tank will have a capacity of 30,000 gallons, and be equipped with sampling ports and safety equipment. A gas circulation mixing system, utilizing gas produced in the digester, will prevent stratification inside the tank.

The mixture inside the tank will be maintained at a temperature of 37 degrees C. Anticipated retention time for the system is 10 days, although this will vary as experimental conditions demand.

3.3.5 Gas Handling System

The proposed gas handling system will consist of standard components. Gas will flow from the top of the digester tank to a scrubber, which will reduce the concentrations of hydrogen sulfide and water. Next, the gas pass through a meter that will monitor production. A compressor pump will send the pressurized methane to a set of underground storage tanks located adjacent to the digester building.

3.3.6 Gas Production and Use

At full operating capacity, and with the increased production expected with the use of cellulose mixes, daily production of methane is anticipated to be from 4 to 6 mcf (thousand cubic feet). The digester system itself will require some of the gas to heat water for three purposes: heating the building housing, the tank and laboratory; heating the contents of the digester tank; and pre-heating the contents of the receiving and holding tank. A heat exchanger will be used to recover some of the heat in the effluent being pumped from the digester tank to the effluent tank. It is expected that, depending on weather conditions and operating levels of the system, about one to two mcf/day of the gas production will be required for these in-system uses.

The remainder of the methane produced, about 2 to 5 mcf a day, will be available for a variety of uses, including heating the Dairy Center's existing office and laboratory building as well as further experimental purposes.

3.3.7 Effluent Handling

In the design of any digester system, particular attention must be given to the handling and disposal of effluent, so as to assist rather than exacerbate the waste management measures of the farm. Special emphasis, therefore, has been placed in this preliminary design stage on the eventual disposal of digester effluent. Rather than consider effluent handling a problem, the proposed project establishes it as a significant research priority.

Two alternative disposal methods have been identified thus far for the MSU digester system:

i) Slurry from the 8,000-gallon effluent tank could be pumped into a small tank truck and spread on the fields adjacent to the digester laboratory building, much like the Dairy Center's liquid manure pit is emptied currently. It should be noted that this method is similar to a conventional municipal waste treatment system, and does not cause pollution. At peak operating capacity, the system is expected to produce about 1,700 pounds of slurry a day, and the effluent tank will need to be emptied about every two days. Engineering calculations conclude that less than one acre of land will be required to spread the slurry for the entire year. The water from the slurry would percolate into the soil and become purified. The organic material remaining on the fields could be dried and collected. Evaluations will be made of the appropriate uses for this residue. One possibility may be that it will provide a potentially-profitable fertilizer. Most of the weed seeds contained in the influent manure likely will be eliminated during anaerobic digestion in the digester tank. Thus, the effluent may be a "weed-seedless" fertilizer that could be sold to nurseries, market gardeners and home gardeners.

ii) Slurry from the effluent tank could be hauled by tank truck to the Bozeman municipal sewage treatment plant, where it would be spread over fields along with the municipal sewage. Presently, the City of Bozeman spreads about 20,000 gallons of slurry over its fields every two days. Waste treatment plant officials have indicated they would be willing to receive and dispose of the effluent slurry from the proposed digester system.

3.3.8 Laboratory Testing

A well-equiped laboratory will be established in the digester building to monitor the biogas production results of the various feedstock mixes, and to insure proper and safe system operation.

Tests on the digester contents will include pH, alkalinity, total volatile acids, percent total solids, percent volatile solids, BOD_5 (5-day biochemical oxygen demand), TOC (total organic carbon), and, occasionally, ammonium ion concentration. Influent and effluent also will be tested for pH, percent total solids, percent volatile solids, BOD_5 and TOC. Additionally, the effluent will be tested for dissolved oxygen.

3.3.9 Safety

All necessary monitoring and safety equipment for the digester system will be used, including safety alarms, a repressurizer, flame traps, drip traps and pressure relief valves.

3.4 Special Design Considerations

Most digester system components discussed above are standard equipment on municipal waste treatment facilities or in previous digester system designs. However, engineering of the MSU system must pay particular attention to the special component and operating requirements under the stress of extremely cold temperatures. The following are considerations that will require special attention at the design stage and/or during operation.

3.4.1 Materials Handling

During the winter, snow will be collected with the manure and also will cover the saucers and fields. The snow could create a freezing problem with the manure, an increase in energy input to the receiving and holding tank, and difficulty in spreading the effluent slurry onto fields.

3.4.2 Shredder

The operation of the shredder is vital to the successful transfer of laboratory conditions to pilot-plant scale conditions. Particle size is expected to be a key variable in the level of biogas production. Thus, the finer the cellulose can be ground, the nearer the pilot-scale plant may approach laboratory results. Existing shredder designs may require modifications so that the desired particle sizes can be achieved.

3.4.3 Grinding Pump

The digester feed pump must be capable of handling granular material without valve blockage or excess wear on moving parts. The experience of digester research groups indicates that a heavy industrial sewage type pump will be needed. The electrical power for this pump will constitute a major power input.

3.4.4 Agitation

Some agitation of the effluent material in the tank is necessary to prevent formation of floating scum and to insure even bacteriological action. Recycling the gas as a stirring agent is the approach most often used in digester design. However, a mechanical stirrer, operated about ten minutes out of the hour, may be more effective at drawing floating materials down into the mass. Also, the input of new materials should be injected at high velocity and directed in such a manner as to suck floating materials down into the fluid mass.

3.4.5 Heat Recovery from the Effluent

Economics dictate that some of the heat from the effluent should be used to heat the incoming materials. It may be considerably easier to heat the mixing and cleaning water than it is to heat the manure water mixture.

This approach also simplifies the main pump requirements.

3.4.6 Water Condensation in the Gas Line

The gas will be leaving the digester at 35 degrees C. and 100 percent humidity. Water will condense out of the gas anytime there is a temperature reduction or pressure increase. This water can easily block pipes and valves if allowed to freeze. Water removal constitutes a major design problem in severely cold climates. The gas lines, hydrogen-sulfide scrubber, gas meter, compressor pump, and water traps should be located in the building or insulated with some heat traces using the digester heating system.

3.5 Estimated Project Costs

Project costs are categorized according to design and construction on the one hand and research operation and maintenance on the other. The design and construction period would be from March 1980 to December 1980. Costs include primarily installed capital items. The research operation and maintenance phase extends for three years from October, 1980 to October, 1983. Principal costs here are for personnel.

TABLE 3-1 TOTAL ESTIMATED COSTS

	1980	1981	1982	1983	TOTAL
I. Design and Construction	$214,438				$214,438
II. Research and Operation		$71,080	$78,189	$86,009	$235,278
					$449,716

TABLE 3-2 DESIGN CONSTRUCTION COSTS

(March 1980 - December 1980)

TOTAL CONSTRUCTION AND DESIGN COSTS

I. Personnel			
	A. Project Director		$13,500
	B. Principal Investigator		3,045
	C. Project Associate: Engineer		7,289
	D. Benefits		4,171
	Total Personnel Costs		$28,005
II. Design and Operation			
	A. Supplies and Typing		$ 900
	B. Communications		150
	C. Travel		1,000
	D. NCAT Consultants		10,000
	E. Engineering Design Consultants		25,000
	Total Design and Operation Cost		$37,050
III. Capital			
	A. Shredder		$ 5,000
	B. 8,000 Gallon Receiving and Holding Tank		2,500
	C. Mixer		2,000
	D. Grinding Pump		5,000
	E. 30,000 Gallon Insulated Digester Tank		15,000
	F. Gas Circulation Mixer		2,000
	G. Gas Scrubber		500
	H. Gas Meter		200
	I. Gas Compressor Pump		5,000
	J. Gas Storage Tanks		1,000
	K. Boiler Tank		2,000
	L. Pump to Effluent Tank		3,000
	M. 8,000 Gallon Effluent Tank		2,500
	N. Assorted Piping		2,000
	O. Safety Equipment		5,000
	P. Heat Exchanger		2,500
	Q. Building (1,000 sq. ft. at $25/sq. ft)		25,000
	R. Laboratory		
	Gas Chromotograph	$10,000	
	Table-top Centrifuge	1,000	
	pH Meter (digital)	1,000	
	Lab Bench with Sink	1,000	
	Still	600	
	Refrigerator	300	
	Hot Water Heater	300	
			14,200
	Subtotal		$94,400
add:	estimated construction labor costs		$20,000
	20% for contingencies		18,880
	Total Capital Installed costs		$133,280
Indirect Cost Recovery (57.5% SWB)			$ 16,103
TOTAL			$214,438

TABLE 3-3 RESEARCH AND OPERATION COSTS

	1981	1982	1983
I. Personnel			
Project Director	$ 3,785	$ 4,164	$ 4,580
Principal Investigator	5,583	6,141	6,755
Research Assistant	6,750	7,425	8,168
University Consultants	5,000	5,500	6,050
Subtotal	$21,813	$23,230	$25,553
Benefits (17.5%)	3,695	4,065	4,472
Personnel Total	$24,813	$27,295	$30,025
II. Operations			
Digester Feedstock	$ 1,000	$ 1,100	$ 1,210
Electricity	200	220	242
Supplies and Typing	500	550	605
Communications	300	330	363
Travel	2,000	2,200	2,420
NCAT Consultants	20,000	22,000	24,200
Operations Total	$24,000	$26,400	$29,040
III. Capital			
Replacement Items	$ 5,000	$ 5,500	$ 6,050
Insurance 2%	3,000	3,300	3,630
Capital Total	$ 8,000	$ 8,800	$ 9,680
Direct Costs Subtotal	$56,813	$62,495	$68,745
Indirect Cost Recovery (57.5% SWB)	$14,267	$15,694	$17,264
TOTAL	$71,080	$78,189	$86,009

4. ECONOMIC ANALYSIS

4.1 Application to a Hypothetical Dairy Farm

This section of the report will present a summary of the economic analysis conducted for the project. A detailed presentation of the assumptions and results of the analysis is provided in Appendix B.

The biogas digester system proposed for the MSU Dairy Center is a research facility, and as such will have significant cost components (such as a laboratory) that would not be included in a system designed for a conventional dairy farm. The real value of the proposed MSU project will be its contribution to the knowledge of optimal manure-cellulose mixtures that maximize biogas production for existing conventional dairies.

The thrust of the economic analysis then, is the application of the anticipated biogas production results from the proposed MSU system to a hypothetical, yet typical, Montana dairy farm. The analysis will clarify the proposed project's significance in terms of economic viability and technology transfer to present Montana dairy farmers.

It should be noted that much of the recent literature concludes that economical biogas digestion systems are possible only with very large dairy herds, 400-head and larger. However, as noted in the Interim Report of the Biogas Conversion Assessment Project, few Montana dairies are this large. Most are relatively small, with less than 200-head. For this reason, the herd size of the hypothetical dairy under consideration is assumed to be the same as the MSU dairy herd: 150-head, with a milking herd of 70.

Two basic points underlying the analysis deserve mention. First, net energy production is the only economic benefit considered. Other benefits such as waste management credits, odor and water pollution control, or increased farm self-sufficiency may be real and significant in specific instances. However, it would be misleading, at this point, to include such credits. No such additional benefits can be anticipated for the proposed MSU system, and none were included in the economic analysis. Thus, for many Montana dairy farmers, the projected analysis may be on the conservative side. Nevertheless, it is possible for these secondary benefits to compensate for any shortfalls between lifetime biogas system costs and conventional energy costs.

Secondly, the economic analysis emphasizes a lifecycle costing approach--what the costs and benefits to the farmer will be over the lifetime of the biogas digester system. It is suggested that the lifecycle costing approach is appropriate in a capital-intensive operation such as dairy farming, where other equipment and assets are discounted in value over time. However, a lifecycle approach demands that assumptions be made about future conditions. Such assumptions, of course, may not turn out to be realistic. Because the assumptions have a significant impact on the results of the economic analysis, it seems prudent to conduct a sensitivity analysis of the key variables under consideration. Thus, a range of possible values for each variable is used to determine how sensitive the results are to changes in the variables. In this report, a sensitivity analysis was done for three key variables:

i) initial capital costs of the digester system;

ii) future price increases for the conventional replacement fuels (propane and natural gas);

iii) the discount (or interest) rate used in standard cost-benefit analysis.

4.2 Capital Costs and Total Annual Costs

The research components of the proposed MSU project will be omitted in a system designed for a conventional dairy farm. Both a new building and laboratory equipment are excluded from this analysis. Also, it is assumed that construction labor costs could be reduced significantly through the use of on-farm labor at zero cost.

Table 4-1 summarizes the estimated capital costs of the digester system applicable to the hypothetical case under consideration. Total installed costs would be about $79,520. Total annual costs of this system, which includes variable and fixed costs, are summarized in Table 4-2. With installed capital costs of $79,520, total annual costs of the biogas system will be about $10,132. The detailed economic analysis presented in Appendix B discusses the assumptions underlying the calculations of annual costs.

4.3 Energy Production and Use

It is assumed that the digester system of the hypothetical dairy will achieve the gross energy production levels anticipated in the proposed MSU project. At the designed plant scale in the pilot project, anticipated gross production is 4 to 6 mcf of methane a day, using manure produced by the 70-head milking herd. In an operating digester system about 1 mcf a day will be required for in-system purposes, primarily hot water heating. Net energy production, therefore, will likely be from 3 to 5 mcf of methane a day.

If the production were maintained 365 days a year, total annual methane production under the proposed system could be as much as 1,825 mcf, or about 1,825 million BTUs for the 70 head herd. This value represents a quantum jump in energy production for a small size dairy herd. A recent study done by the ECOTOPE Group, for example, estimated net energy production of 687.3 million BTUs a year for a 100-cow dairy using a conventional manure-only digester system. (ECOTOPE Group, 1978, p. 58).

TABLE 4-1 ESTIMATED INSTALLED COSTS OF BIOGAS DIGESTER SYSTEMS ON HYPOTHETICAL DIARY FARM

1.	Shredder	$5,000
2.	8,000 Gallon Receiving and Holding Tank	2,500
3.	Mixer	2,000
4.	Grinding Pump	5,000
5.	30,000 Gallon Insulated Digester Tank	15,000
6.	Gas Circulation Mixer	2,000
7.	Gas Scrubber	500
8.	Gas Meter	200
9.	Gas Compressor Pump	5,000
10.	Gas Storage Tanks	1,000
11.	Boiler Tank	2,000
12.	Pump to Effluent Tank	3,000
13.	8,000 Gallon Effluent Tank	2,500
14.	Assorted Piping	2,000
15.	Safety Equipment	5,000
16.	Heat Exchanger	2,500
	Subtotal	$55,200
add:	estimated construction labor costs	5,000
	20% for contingencies	11,040
	15% for engineering	8,280
	TOTAL Estimated Installed Costs	$79,520

TABLE 4-2 ESTIMATED TOTAL ANNUAL COSTS OF 30,000 GALLON CAPACITY BIOGAS DIGESTER SYSTEM

VARIABLE COSTS	
Labor (2 hr./day at $4/hr. from October 1 - May 31)	$1,944
Manure and Other Feedstocks	-0-
Electricity	100
Total Variable Costs	$2,044
FIXED COSTS	
Capital Investment[1]	$4,408
Taxes and Insurance[2]	3,180
Maintenance	500
Total Fixed Costs	$8,088
Total Annual Costs	$10,132

1. Annual capital equivalent payment of $79,500 capital investment at 1% real rate (9% money rate including 8% inflation) for 20 years.

2. 4% of installed capital costs.

In reality, of course the digester system will not be operating at full capacity all year. Throughout the summer months, for example, the herd will be on grazing pasture most of the day, and therefore, much of the manure cannot be easily collected. Correspondingly, though, energy demand on the dairy is minimal over the summer. For these reasons, the economic analysis assumes that the digester is used from October 1 to May 31, and is idle from June 1 to September 30.

Table B-1 in Appendix B summarizes the monthly and annual contribution of the biogas system to the total heating requirements of the dairy. Thus, net methane use from the digester system will vary from 723 mcf a year to 1,085 mcf a year, depending on the daily production level achieved.

Table 4-3 summarizes the present costs of this energy, and compares it to the present costs of conventional heating fuels used on dairies: natural gas and propane. Note that even at maximum anticipated levels of daily methane production from the digester, 5 mcf, the cost of $9.34 per million BTU is still far greater than propane at present costs.

But it is reasonable to expect the propane and natural gas prices to increase over time, while the costs of methane from the digester remain constant over time. The next step in the analysis, then, is to compare total heating costs, in terms of present value costs, over the lifetime of the digester system.

4.4 Lifecycle Energy Costs and Benefits

Appendix B develops the detailed calculations of the lifecycle energy costs and benefits for the proposed biogas digester system. These calculations are summarized in Tables B-2 to B-7, in which a sensitivity analysis is conducted to determine the impact of changes in:

TABLE 4-3 PROJECTED COSTS PER 10^6 BTUS OF NET ENERGY

Assume: total annual costs = $10,132

DAILY PRODUCTION[1]	3 mcf	4 mcf	5 mcf
Annual Use on Dairy[2]	723 mcf	904 mcf	1,085 mcf
Cost per 10^6 BTU	$14.01	$11.21	$9.34

vs. PRESENT FUELS: Natural Gas[3]: $2.40/$10^6$ BTU
Propane[4]: $5.00/$10^6$ BTU

1. Estimated low, medium and high levels of daily methane production from proposed system
2. From October 1 - May 31: see Appendix B for details of monthly energy use data.
3. Assuming 1 mcf of natural gas = 1 x 10^6 BTU
4. Average price = 46¢/gal., 1 gal. = 92,000 BTU.

i) initial capital costs;
ii) future increases in prices for conventional energy;
iii) the discount rate; and
iv) the conventional fuel replaced by the biogas.

The tables clearly indicate that the lifecycle economics of the biogas system are dominated primarily by, firstly, initial capital costs of the system and, secondarily, by future energy price increases. However, the biogas system can be considered a viable economic venture only if the methane is to replace a presently high-priced fuel such as propane. Under none of the assumption-combinations listed in Tables B-2 to B-7 does the biogas system create net positive benefits over the 20 year period of analysis when natural gas is the conventional fuel to be replaced. For the cases in which propane is to be replaced, the results, briefly, are:

(i) Digester System Costs of $40,000 (Table B-2): If a system as described in section III of this report can be constructed for about $40,000, then it will provide net benefits, in terms of energy expenditure savings, over the system's lifetime. This projection is true even for the relatively conservative assumption that propane prices will increase, in real terms, by only 2%. The choice of discount rate affects only the magnitude of the benefit, not whether there is a positive benefit or not.

(ii) Digester System Costs of $78,000 (Table B-4): A $78,000 system will provide lifecycle benefits from its energy production only if conventional fuels increase in price at the relatively high real rate of 7 percent a year. Under the other two assumptions about energy price increases, the \$78,000 biogas system does not generate energy expenditure savings for the farmer. Again, the choice of a discount rate does not significantly affect the results of the calculations.

(iii) Digester System Costs of \$100,000 (Table B-6): If the proposed system in reality costs \$100,000 instead of \$78,000, then the investment will not break-even over the lifetime of the system, even under the assumption that propane increases by 7 percent a year in real terms.

4.5 Conclusions

The thrust of the lifecycle costing analysis is presented in the data listed in Column (vii) of Tables B-2 to B-7 in Appendix B. The values represent the lifecycle benefits, from energy production alone, of the biogas system (and backup fuel) when compared to heating without the biogas system. As the discussion in section 4.4 indicated, a \$40,000 biogas system achieving the production levels expected in the MSU research digester, appears to be viable economically at this point. However, at higher capital costs, negative values appear in Column (vii), representing the present value shortfall in the system's economic feasibility.

As mentioned previously, however, other benefits of the biogas digester are possible: improved waste management; odor and water pollution control; fertilizer sales; and tax credits. All these are possible in specific circumstances. Thus, the negative values in Column (vii) of the lifecycle costing tables indicate the magnitude of the economic gap that needs to be made up by these other credits before the biogas system becomes at least a break-even proposition to the dairy farmer at this time.

Clearly, these gaps have important public policy implications. In one sense, they are a measure of the present degree of subsidization that must be provided (in some form) if the kind of biogas digester system proposed for the MSU Dairy Center is to be considered for widespread adoption in the dairy farm sector. It should be noted that the annual value of these "other" credits need not be large in order for them to make a difference over the 20-year lifetime of the system. For example, if the digester provides the dairy farmer with $2,000 a year savings in waste management handling, and another $1,000 a year in fertilizer sales, and if these benefits are constant in real terms over the life of the system, then their present value lifecycle benefits total more than $54,000. In most cases, this level of benefits would be enough to make a $78,000 digester system viable economically, even under low growth rates for conventional energy prices. Even the $100,000 digester system will provide net benefits given a seven percent annual fuel price increase, with this level of non-energy benefits.

Likewise, other public policy measures could be tested in a similar manner to determine their probable impact on the economic cost/benefit analysis of biogas digester systems. The lifecycle cost analysis underlines the importance of testing optimal designs and components in order to reduce the high initial capital costs of the system and so move biogas digestion closer to widespread on-farm use.

Most importantly, the economic analysis suggests that the proposed research project could have far-reaching implications for small-to-medium size dairy farms. The significant increase in methane production expected with the appropriate manure-cellulose combinations will allow biogas digester systems to approach economic feasibility for small dairy herds. Biogas systems need no longer be confined to very large farms or feedlots. Rather, with only relatively minor non-energy credits, such as waste handling benefits, biogas systems may be an economical venture for dairy farms with less than 200 head — a size approximating the great majority of Montana dairies.

5. FUNDING

Funding for the proposed MSU Research Biogas Digester project will be pursued in the fall of 1979 from both state and federal sources: the Montana Alternative Renewable Energy Sources Program, funded by a coal severance tax authorized by Senate Bill 86 in 1975; and the Solar Energy Research Institute, in Golden, CO.

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APPENDIX A

PROFILE OF EXISTING MONTANA STATE UNIVERSITY DAIRY CENTER OPERATIONS

A.1 General Operations

The MSU Dairy Center, part of the University's Agriculture Experimental Station, was built about 1956, and serves both a research and educational role. Presently, there are about 150 head of cattle, all Holsteins, with a milking herd of 70. The cows are milked twice a day, and the milk sold commercially to dairies in Great Falls and Billings, Montana. There are three full-time employees: one herdsman and two milkers.

Figure A-1 illustrates the general layout of operations at the dairy center.

A.2 Manure Disposal

Although no precise data are available on how much manure is produced and collected at the dairy center, it is generally accepted that a full-grown cow will produce about 80 pounds of manure a day. Given that some of the 150-head herd are calves, and that not all of the manure will be collected from the loafing sheds, it seems reasonable to assume that at least 4 tons of manure would be collected every day and stored on the 3 temporary pads on the west side of the lots. (The proposed biogas digester system would, at peak operating capacity, utilize about 70 percent of this manure total). The concrete floors of the lots are cleared of manure daily, with the use of a rear-mounted scraper on a tractor. Because the lot floors are concrete, there is little dirt or straw collected along with the manure. An estimated 80 to 90 percent of the manure mix on the temporary storage piles is manure; the rest would be straw. This will change, of course, after a heavy snowfall, when the tractor will scrape away much snow as well as manure.

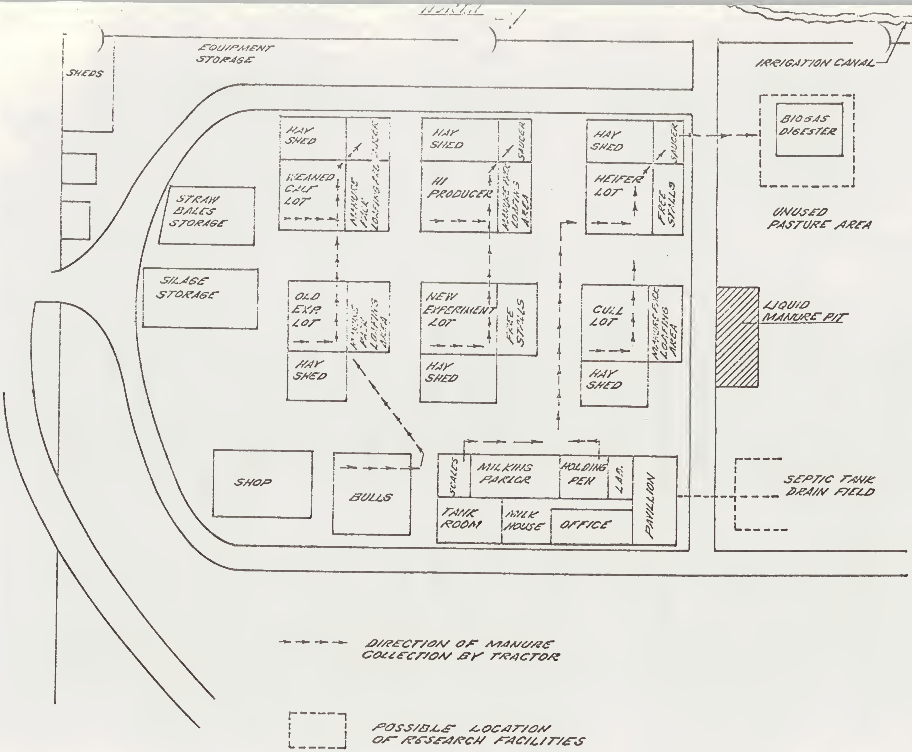


FIG. A-1 M.S.U. - DAIRY CENTER OVERVIEW

A small amount of manure is dropped by the cows in the milking parlor. This manure is drained, along with the hot water and detergent used to wash the milking equipment and parlor floor, to the liquid manure pit located just north of the loafing sheds. The pit is occasionally emptied by a small (1,000 gallon) tank truck, and the effluent is spread on fields as a fertilizer.

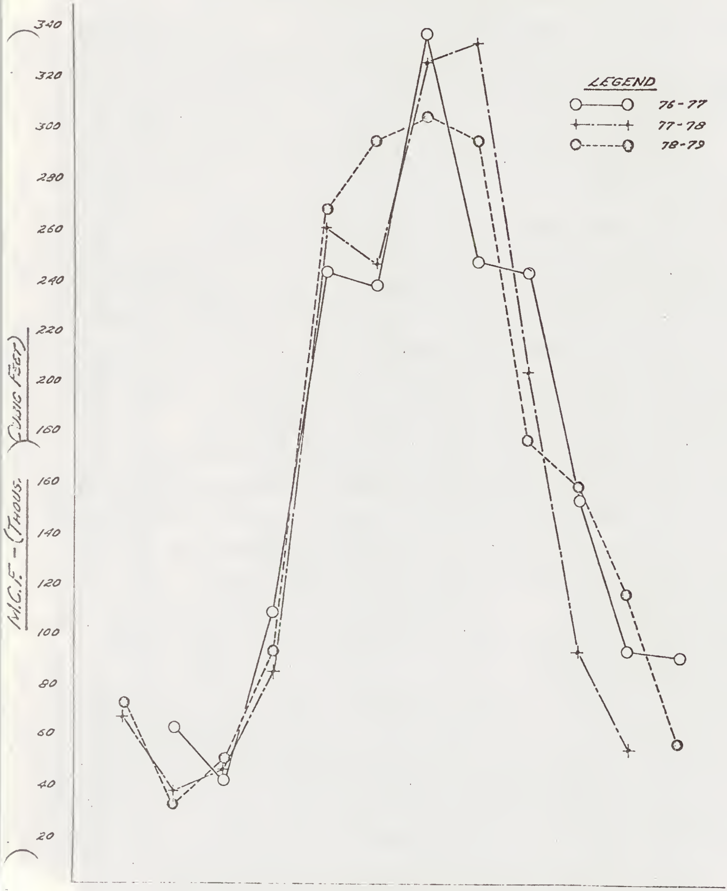
A.3 Present Energy Use

Excellent data is available on energy use at the MSU Dairy Center from past utility bill records. The energy use profile of the MSU Dairy differs from most dairy farms in several ways. Gasoline and diesel fuel play an insignificant role, because the dairy center owns only one small tractor, the remainder of any required equipment being owned by the MSU Agriculture Experimental Station as a whole. As well, natural gas is used for space heating and hot water heating purposes because, unlike most dairies, the center is adjacent to a built-up area and existing natural gas lines. Most dairy farmers use either propane or heating oil for heating purposes, at a much higher cost than if natural gas were available to them. Present natural gas costs to the dairy are about $2.40/mcf. Finally, there is no residential home at the MSU Dairy Center, and so only a minor amount of electricity (a flat rate of 284 KWH a month) is used for lighting and milking equipment.

On average over the last three years, the dairy center has used 1,800 to 1,900 million BTU's in the form of natural gas and electricity, the former accounting for nearly 95 percent of total energy use. Figure A-2 illustrates the monthly fluctuations of the natural gas use over the last three years. Utility bills in 1978-79 totaled about $4,300.

FIG. A-2 — MONTHLY NATURAL GAS USE ~ MSU DAIRY CENTER

BY FISCAL YEAR: JULY 1 TO JUNE 30



APPENDIX B

DETAILED ECONOMIC ANALYSIS AND ASSUMPTIONS

B.1 Dairy Farm Operations

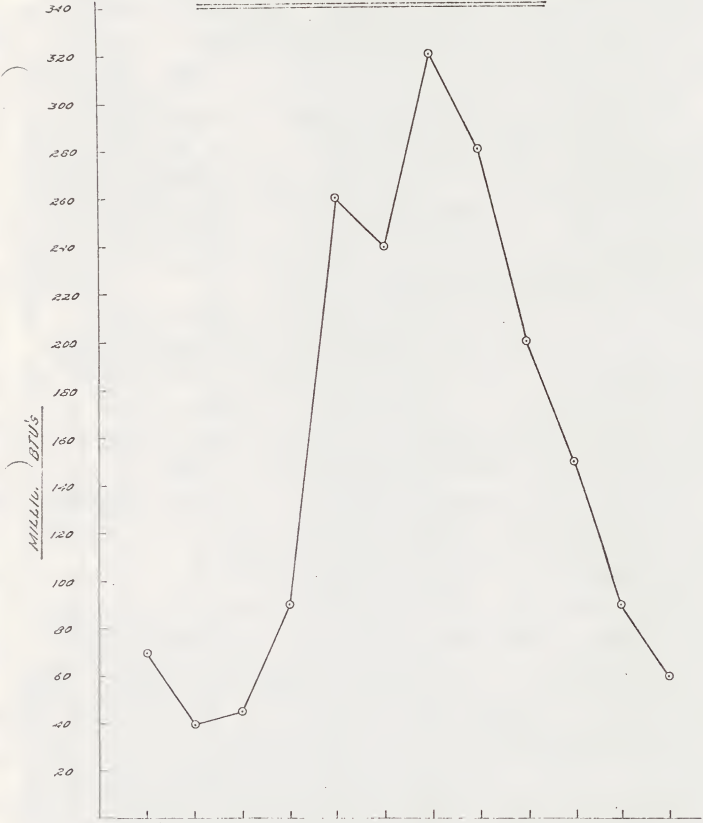
As the interim report of the Biogas Conversion Assessment Project noted, most dairy farms in Montana are relatively small in size, less than 200 head. For this reason, the analysis assumes that the herd size of the hypothetical dairy farm under consideration is the same as the MSU Dairy herd: 150 head, with a milking herd of 70.

B.2 Capital Costs and Annual Costs

Capital costs for the digester system were summarized in Table 4-1. Two assumptions were made in these calculations: the digester tanks and gas handling system were housed in an existing shed or barn building on the farm, so that no new building needed to be constructed; construction labor costs include a component of on-farm labor which costs the farmer nothing (that is, has a zero opportunity cost).

Total annual costs were shown in Table 4-2. Annual labor costs were assumed to be two hours a day, at $4 an hour, for the eight months of system operation. The majority of the labor time will be spent on: transporting manure from a temporary storage pile to the system's holding tank; shredding and handling of cellulose mix; monitoring the health of the digester system; and, every few days, spreading the effluent on the fields. In Table 4-2, digester feedstocks are given a zero cost. Their collection and storage may be part of existing farm operations, as in the case of manure and straw. Other feedstocks, such as waste paper, spoiled feed and spoiled milk, have zero opportunity costs, and would otherwise be wasted. (This also assures that collection of these latter feedstocks has a negligible cost).

FIG. B-1 - MONTHLY ENERGY USE FOR HYPOTHETICAL DAIRY FARMS HEATING PURPOSES*



*BASED ON 3-YEAR AVERAGE 1976-77 TO 1978-79 FOR MSU DAIRY. (SEE APPENDIX)

B.3 Energy Demand

Energy use on the hypothetical dairy farm is assumed to be similar to the MSU Dairy Center, discussed in Appendix A. About 1,845 million BTU's a year, or 90 to 95 percent of total energy use, is demanded for heating purposes (space and hot water heating). This high figure reflects the extremely cold climatic conditions in Montana. Figure B-1 illustrates the monthly distribution of this energy demand, based on the monthly demand records of the MSU dairy noted in Appendix A.

Recall that net daily methane production from the digester system is expected to be from 3 mcf to 5 mcf. Table B-1 summarizes the monthly contribution of the digester system to total heating demand at the dairy, depending on the biogas system's production level. It is assumed that: total annual energy demand for heating purposes is 1,845 million BTU's; the biogas system operates from October 1 to May 31; and the energy demand for heating purposes from June 1 to September 30 is 215 million BTU's.

Note that if the daily production of the biogas system is 3 mcf a day of methane, total annual contribution to the dairy's heating needs is 723 million BTU's, or about 39 percent of demand. About 49 percent of annual demand can be met if the system produced 4 mcf a day. At the maximum anticipated level of daily production of 5 mcf a day, 1,085 million BTU's, or 59 percent of the heating demand, will be met by the biogas system. At this level, only 760 million BTU's will be required in the form of backup fuel from the conventional sources of propane or natural gas.

B.4 Economic Assumptions

The following assumptions were used in the analysis:

i) The biogas system has, on average, a lifetime of 20 years;

ii) The inflation rate is 8 percent a year;

iii) Energy consumption patterns remain constant over the period of

TABLE B-1 MONTHLY CONTRIBUTION OF BIOGAS SYSTEM TO HYPOTHETICAL DAIRY FARM'S ENERGY USE

Assumptions: Biogas system operates: October 1 - May 31
Energy demand from June 1 - September 1: 215×10^6 BTU.

	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	AP.	MAY	OTHER	(MBTU) TOTAL
DEMAND (x 10^6 BTU)	90	260	240	320	280	200	150	90	215	1,845
DEMAND FROM DAILY BIOGAS SYSTEM PROD. (i) 3×10^6BTU	90	90	93	93	84	93	90	90	0	723 (39%)
BACKUP NEEDED	0	170	147	227	196	107	60	0	215	1,122
(ii) 4×10^6BTU	90	120	124	124	112	124	120	90	0	904 (49%)
BACKUP NEEDED	0	140	116	196	168	76	30	0	215	941
(iii) 5×10^6BTU	90	150	155	155	140	155	150	90	0	1,085 (59%)
BACKUP NEEDED	0	110	85	165	140	45	0	0	215	760

analysis, at 1,845 million BTU's a year (for heating purposes);

iv) The two replacement fuels have the following 1979 prices per one million BTU's

natural gas: $2.40

propane: $5.00

v) The biogas system operates at full capacity from October 1 to May 31, and then is shutdown from June 1 to September 30;

vi) Annual operating and maintenance costs remain constant in real terms;

vii) Throughout the analysis, calculations were made in real terms, which remove from analysis changes resulting only from inflation; this focuses attention on the real, as opposed to money, costs to the farmer; for example, a 9 percent discount rate will include the 8 percent inflationary factor, resulting in a real discount rate of 1 percent.

As noted in section 4 of the report, a sensitivity analysis was performed for three key variables. The range of values assumed for the variables were:

i) Future price increases for conventional energy sources
    a) constant in real terms (8% a year including inflation);
    b) 2% a year in real terms (10% including inflation);
    c) 7% a year in real terms (15% including inflation).

ii) Discount rates
    a) 1% in real terms (9% including inflation);
    b) 4% in real terms (12% including inflation);
    c) 10% in real terms (18% including inflation).

iii) Installed Capital Costs

a) \$40,000, with total annual costs of \$6,400

b) \$78,000, with total annual costs of \$10,000.

c) \$100,000, with total annual costs of \$12,000.

B.5 Lifecycle Costs and Benefits

With the above assumptions and data on energy demand supplemented by biogas, standard lifecycle costing analysis was applied to determine the costs and energy benefits of the biogas system to the hypothetical dairy farm.

The following formulas were used:

(i) for a stream of constant annual costs:

$$PV = a\left[\frac{(1 + i)^{n} - 1}{i\,(+ i)^{n}}\right]$$

Where: PV = present value of stream of costs

a = constant annual payments

i = social discount rate

n = number of years

(ii) for a stream of growing costs:

$$PV = r\left[\frac{1 + g}{i - g}\right] \quad 1 - \left[\frac{(1 + g)^{n}}{(1 + i)^{n}}\right]$$

Where: r = initial value of costs

g = annual growth rate

Tables B-2 through B-7 summarize the lifecycle costing calculations undertaken for the biogas system, under the assumption that daily production is 5 mcf of methane. Each talbe represents one of six combinations of total system costs and conventional fuel replaced:

B-2 digester installed capital costs = $40,000; replaced fuel is propane;

B-3 $40,000/natural gas;

B-4 $78,000/propane

B-5 $78,000/natural gas;

B-6 $100,000/propane;

B-7 $100,000/natural gas;

In each of the tables: Columns (i) and (ii) illustrate the sensitivity analysis applied to conventional energy price increases, and the discount rate, respectively.

Column (iii) indicates the present value 20-year costs of heating with conventional fuel — that is, what the dairy farmer would pay for heating purposes in the absence of the biogas digester system.

Column (iv) is the present value cost of the annual capital and operating costs of the biogas system over 20 years.

Column (v) is the present value of the 20-year stream of costs of conventional fuel required as backup to the biogas system.

Column (vi) is the sum of columns (iv) and (v), and represents the total lifecycle energy costs for heating on a farm using the biogas system.

Column (vii) is the difference between columns (iii) and (vi), and represents lifecycle biogas system benefits.

A positive value in column (vii) would indicate that under that particilar set of assumptions, energy production from the biogas system results in net economic savings to the dairy farmer. A negative value in column (vii) represents the shortfall in the economic break-even point for the biogas system when compared to heating with conventional fuels (considering only energy production benefits).

Section 4.4 of the report discusses results of the lifecycle costing analysis.

TABLE B-2 LIFECYCLE COSTS AND BENEFITS

Digester System Costs: $40,000
Replacement Fuel: Propane

(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)
		Conventional Dairy	Dairy with Biogas Digester			
Annual Real Energy Price Increases	Real Discount Rate	Lifecycle Heating Costs	Lifecycle Costs of Annual Biogas System Costs	Lifecycle Costs of Conventional Back-up Fuel	Total Lifecycle Heating Costs [(iv)+ (v)]	Life Time Biogas System Energy Benefits [(iii) - (vi)]
7%	.01	$357,219	$115,492	$147,147	$262,639	+$94,580
	.04	$252,057	$86,978	$103,828	$190,806	+$61,251
	.10	$139,769	$54,487	$57,574	$112,061	+$27,708
2%	.01	$204,939	$115,492	$84,419	$199,911	+$5,028
	.04	$151,415	$86,978	$62,371	$149,349	+$2,066
	.10	$91,640	$54,487	$37,749	$92,236	+596
Constant	.01	$166,472	$115,492	$68,574	$184,066	-$17,594
	.04	$125,370	$86,978	$51,643	$138,621	-$13,251
	.10	$78,538	$54,487	$32,352	$86,739	-$8,201

TABLE B-3 LIFECYCLE COSTS AND BENEFITS

Digester System Costs: $40,000
Replacement Fuel: Natural Gas

(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)
		Conventional Dairy	Dairy With Biogas Digester			
Annual Real Energy Price Increases	Real Discount Rate	Lifecycle Heating Costs	Lifecycle Costs of Annual Biogas System Costs	Lifecycle Costs of Conventional Back-up Fuel	Total Life-cycle Heating Costs [(iv) + (v)]	Lifetime Biogas System Energy Benefits [(iii) - (vi)]
7%	.01	$171,465	$115,492	$70,631	$186,123	-$ 14,658
	.04	$120,987	$86,978	$49,838	$136,816	-$15,829
	.10	$67,089	$54,487	$27,636	$82,123	-$15,034
2%	.01	$98,371	$115,492	$40,521	$156,013	-$57,642
	.04	$72,679	$86,978	$29,938	$116,916	-$44,237
	.10	$43,987	$54,487	$18,119	$72,606	-$28,619
Constant	.01	$79,906	$115,492	$32,915	$148,407	-$68,501
	.04	$60,178	$86,978	$24,789	$111,767	-$51,589
	.10	$37,698	$54,487	$15,529	$70,016	-$32,318

TABLE B-4 LIFECYCLE COSTS AND BENEFITS

Digester System Costs: $78,000
Replacement Fuel: Propane

(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)
		Conventional Diary	Dairy With Biogas Digester			
Annual Real Energy Price Increases	Real Discount Rate	Lifecycle Heating Costs	Lifecycle Costs of Annual Biogas System Costs	Lifecycle Costs of Conventional Back-up Fuel	Total Lifecycle Heating Costs [(iv) + (v)]	Lifetime Biogas System Energy Benefits [(iii) - (vi)]
7%	.01	$357,219	$180,457	$147,147	$327,604	+$29,615
	.04	$252,057	$135,903	$103,838	$239,731	+$12,326
	.10	$139,769	$85,136	$57,574	$142,710	+$2,941
2%	.01	$204,939	$180,457	$84,419	$264,876	-$59,937
	.04	$151,415	$135,903	$62,371	$198,274	-$46,859
	.10	$91,640	$85,136	$37,749	$122,885	-$31,245
Constant	.01	$166,472	$180,457	$68,574	$249,031	-$82,559
	.04	$125,370	$135,903	$51,643	$187,546	-$62,176
	.10	$78,538	$85,136	$32,352	$117,488	-$38,950

TABLE B-5 LIFECYCLE COSTS AND BENEFITS

Digester System Costs: $78,000
Replacement Fuel: Natural Gas

(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)
		Conventional Dairy	Dairy with Biogas Digester			
Annual Real Energy Price Increases	Real Discount Rate	Lifecycle Heating Costs	Lifecycle Costs of Annual Biogas System Costs	Lifecycle Costs of Conventional Back-up Fuel	Total Lifecycle Heating Costs [(iv) + (v)]	Lifetime Biogas System Energy Benefits [(iii) - (vi)]
7%	.01	$171,465	$180,457	$70,631	$251,088	-$79,623
	.04	$120,987	$135,903	$49,838	$185,741	-$64,754
	.10	$67,089	$85,136	$27,636	$112,772	-$45,683
2%	.01	$98,371	$180,457	$40,521	$220,978	-$122,607
	.04	$72,679	$135,903	$29,938	$165,841	-$93,162
	.10	$43,987	$85,136	$18,119	$103,255	-$59,268
Constant	.01	$79,906	$180,457	$32,915	$213,372	-$133,466
	.04	$60,178	$135,903	$24,789	$160,692	-$100,514
	.10	$37,698	$85,136	$15,529	$100,665	-$62,967

TABLE B-6 LIFECYCLE COSTS AND BENEFITS

Digester System Costs: $100,000
Replacement Fuel: Propane

(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)
		Conventional Dairy	Dairy With Biogas Digester			
Annual Real Energy Price Increases	Real Discount Rate	Lifecycle Heating Costs	Lifecycle Costs of Annual Biogas System Costs	Lifecycle Costs of Conventional Back-up Fuel	Total Lifecycle Heating Costs [(iv) + (v)]	Lifetime Biogas System Energy Benefits [(iii) - (vi)]
7%	.01	$357,219	$216,548	$147,147	$363,695	-$6,476
	.04	$252,057	$163,084	$103,828	$266,912	-$14,855
	.10	$139,769	$102,163	$57,574	$159,737	-$19,968
2%	.01	$204,939	$216,548	$84,419	$300,967	-$96,028
	.04	$151,415	$163,084	$62,371	$225,455	-$74,040
	.10	$91,640	$102,163	$37,749	$139,912	-$48,272
Constant	.01	$166,472	$216,548	$68,574	$285,122	-$118,650
	.04	$125,370	$163,084	$51,643	$214,727	-$89,357
	.10	$78,538	$102,163	$32,352	$134,515	-$55,977

TABLE B-7 LIFECYCLE COSTS AND BENEFITS

Digester System Costs: $100,000
Replacement Fuel: Natural Gas

(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)
		Conventional Dairy	Dairy With Biogas Digester			
Annual Real Energy Price Increases	Real Discount Rate	Lifecycle Heating Costs	Lifecycle Costs of Annual Biogas System Costs	Lifecycle Costs of Conventional Back-up Fuel	Total Lifecycle Heating Costs [(iv) + (v)]	Lifetime Biogas System Energy Benefits [(iii) - (vi)]
7%	.01	$171,465	$216,548	$70,631	$287,179	-$115,714
	.04	$120,987	$163,084	$49,838	$212,922	-$91,935
	.10	$67,089	$102,163	$27,636	$129,799	-$62,710
2%	.01	$98,371	$216,548	$40,521	$257,069	-$158,698
	.04	$72,679	$163,084	$29,938	$193,022	-$120,343
	.10	$43,987	$102,163	$18,119	$120,282	-$76,295
Constant	.01	$79,906	$216,548	$32,915	$249,463	-$169,557
	.04	$60,178	$163,084	$24,789	$187,873	-$127,695
	.10	$37,698	$102,163	$15,529	$117,692	-$79,994

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